

*et al.* (1969). If water is present and amphibole crystallizes then addition of appropriate amounts of amphibole, pyroxene, calcic plagioclase and minor magnetite could satisfy the composition trends. However this model is not as efficient as the eclogite model and the suppression of crystallization of plagioclase in the presence of water makes it unlikely that sufficient of this phase could be available to satisfy the higher  $\text{Al}_2\text{O}_3$  content of the basaltic andesite compared with the andesite.

The eclogite model proposed satisfactorily explains the major element chemistry of the second period of eruption on Fiji. It remains to be seen whether the trace element distributions, in particular the rare earth elements, are also satisfied by the eclogite model. Thus because garnet readily accommodates the heavier rare earth elements, any fractionation process involving extraction of significant proportions of garnet to produce dacite from andesite, should result in a more fractionated rare earth pattern (enriched in light rare earth elements) in the dacite, when compared with the andesite pattern. Investigations are under way to determine if this is the case (Gill, 1971, pers. comm.).

### Conclusions

This experimental study illustrates the significant effect of the presence of water on the crystallization of a typical calc-alkaline andesite at high pressures. It is relevant to models for the derivation of andesite magma from partial melting of the downgoing hydrous lithosphere, an essential tectonic component in the concept of the new global tectonics. The study is based on a natural calc-alkaline andesite composition from the second period of eruption on Fiji (Gill, 1970) and may be applied directly to the interpretation of genetic links between rock types of differing chemistry occurring in this eruptive cycle.

The presence of increasing amounts of water (from 0–10% by weight) has a large effect on lowering the liquidus. This effect is most marked for the first few percent of water added. Thus the liquidus with 2% water present is about 100° C below the anhydrous value while with 10% water it is only lowered a further 150° C. In the present study from 9–36 kb, the water saturated state was not reached on the liquidus. However a separate vapour phase was observed a few degrees below the liquidus at 9 kb with 10%  $\text{H}_2\text{O}$  added.

This demonstrates the quite modest temperatures of 1200–1300° C at which an andesite magma may be obtained by melting in the presence of minor water at depths up to 120 km. When allied with the thermal models and associated melting postulated in a downgoing slab (Fitton, 1971) it is apparent that andesite magmas may only be derived in the upper kilometre of the slab, at greater than 60 km depth, unless magmas are derived with >10% water by weight. Fitton (1971) emphasized that such conclusions are based on several assumptions which may need refinement as more data become available. In particular, the rate of movement of the downgoing slab is critical.

Variation in fractionation controls with depth and water content are caused by the changing nature of the major crystallizing phases. Under dry conditions clinopyroxene and plagioclase dominate at low to intermediate pressures, changing to garnet, clinopyroxene and quartz at higher pressures. The early appearance

of quartz under anhydrous conditions at high pressure supports the conclusion of Green and Ringwood (1968) that the andesite liquidus occurs in a low temperature trough between more basic and more acid compositions at  $>25$  kb. Thus for these conditions it is impossible to obtain a liquid with more than about 62%  $\text{SiO}_2$  by partial melting of an eclogite parent. With the addition of water, the crystallization sequence changes markedly. At low pressure amphibole-clinopyroxene control the fractionation trends (plagioclase is depressed to near the solidus) giving some decrease in Mg/Fe (unless minor magnetite also crystallizes) and in K/Na. At intermediate pressures garnet, clinopyroxene and amphibole govern the fractionation trends and result in minor Mg/Fe decrease and moderate K/Na increase. At high pressure ( $>25$  kb) garnet and clinopyroxene control fractionation trends (quartz appearance depressed to near the solidus) producing marked increase in Si, K/Na but very little Mg/Fe decrease.

The latter fractionation model explains most satisfactorily the major element chemistry of rock types of the second period of eruption on Fiji. The major magma to be erupted is andesite. This may be derived by dry or near-dry melting of the under-thrust lithosphere (now eclogite) at depths of  $\sim 100$  km. The more acid fractionates may result from minor hydrous melting, or by hydrous fractional crystallization of an earlier derived andesite. The requisite hydrous conditions may well be obtained near the roof of some very deep-level andesite magma chamber, where water and other volatiles become concentrated. The eclogite model provides the most efficient mechanism for Si enrichment and can explain the Al and Mg/Fe values more satisfactorily than any model of fractionation at shallower levels.

When the results are viewed in terms of a coherent picture of magma genesis from the down-thrust lithosphere the following points may be made:

(1) The first stage of melting at depths of  $<80$  km involves hydrous melting of the upper part of the lithosphere; subsequent rise of this magma into the overlying pyrolite wedge instigates melting in this wedge, followed by deep-level mixing of magmas, producing members of the island arc tholeiitic series (Jakš and Gill, 1970). Simple melting of the pyrolite wedge cannot explain the trace element distribution in this series (Gill, 1970; Jakš and Gill, 1970). Fitton (1971) proposed that the breakdown and melting of amphibole in a hydrous amphibolitic lithosphere produced the island arc tholeiitic series. Analyses of amphibole in the present work and in Green and Ringwood (1968) indicate that the K/Na ratio for the amphibole is appropriate for this process. The difficulty with this proposal is that it would involve near complete melting of the lithosphere to produce the island arc tholeiitic series, where the most abundant rock type has a silica mode of 53% (Jakš and Gill, 1970).

(2) The second stage of melting of the now near-anhydrous lithosphere at  $>80$  km depth produces a typical calc-alkaline andesite, or, in local areas of hydrous melting (or crystallization), a dacite. Temperatures of  $>1300^\circ\text{C}$  are required to produce andesite under these conditions. This is high when compared with thermal models for the underthrust lithosphere (Oxburgh and Turcotte, 1969; Fitton, 1971).

(3) The final stage of melting occurs at  $>150$  km depth. This stage is still governed by eclogite fractionation, producing silica enrichment in this third